Preferably, the illuminating beam forms an abrupt edge of illumination at a front edge of illumination 38, providing steep rise in the signal responsive to the illumination of the edge of an incoming sheet of paper. Preferably, the illuminating beam also forms a straight edge of illumination at an exit edge of illumination 40. In some preferred embodiments of the invention, tapering of the edges of the beam is used to decrease beam side-lobes. This tapering and the formation of the edge itself are preferably produced by phase-contouring of the lens or using varied amplitude-transmission function, as known in the art of laser beam shaping.

Preferably, object 9 and grating 32 are situated well within the coherence length of source 10 such that the LO and reflected beams are coherent at sensor 20. Placing object 9 and gating 32 at a spacing greater than the coherence length apart, reduces the signal to noise level of the determination.

Object 9 (i.e., the surface of the paper or other moving object) is preferably diffusive, thus the illumination onto object 9 is reflected in a generally broad space angle. Essentially only the reflection parallel to the direction of the diffracted LO from grating 32 interferes with the LO focused on sensor 20. Preferably, at least part of the reflection from object 9 which interfere with a LO field, overlaps the LO beam.

Thus, preferably the spacing between the object and the grating is bounded by $H < D/\tan(\alpha)$, where H is the optical path between the grating and the object, D the beamwidth along the motion measurement direction, and α is the angle between illuminating beam and the LO beam direction

Typical dimensions and values used in a practical device are source wavelength 850 nm, beam width 2 mm, height above sheet 0-5 mm, grating pitch Λ=10 micrometer and overall detector height dimension of 5-10 mm from the moving object. For a paper velocity V=500 mm/sec this results in a Doppler frequency $F = V/\Lambda = 50$ kHz. Of course, other wavelengths, spacings, beam width, etc., will occur to practitioners of the art and are suitable for other preferred embodiments of the invention. Such dimensions allow for determination of the time of arrival of the leading edge of the sheet and the time of exit of the trailing edge of the sheet to within 0.5/v sec and more preferably to within 0.1/v sec, where v is the velocity of the sheet.

Fig. 2A illustrates the use of detector 8 to detect the rear edge of object 9, in accordance with a preferred embodiment of the invention. In some preferred embodiments of the invention, in which only trailing edge detection is desired, sensor 20 may be omitted and the beam passing through grating 32 may be formed to provide only the illumination sensor 24 to detect the trailing-edge of the object, as it exits the illumination beam.

Trailing edge detection, as shown in Fig. 2A is similar to that used for front-edge detection, however, the velocity information gathered in the measurement of sensor 20 may be used to improve the detection by reducing the noise bandwidth.

The signal at sensor 24 rises sharply when the reflection from the front edge of the object in the direction of the LO beam starts to overlap the LO beam reflected from grating 32, as shown in Fig. 2B. Thus, the delay between the rise of sensor 20 signal and the rise of sensor 24 signal depends on the spacing between the grating 32 and the object 40 according to $T_H = H\tan(\alpha)/V$, where T_H is the delay between the signals, H the spacing between grating 32 and object 40, V the velocity of object 40 and α the diffraction angle to sensor 24. This relation enables to estimate the object spacing from the grating from the delay between the signals and from the velocity information. Here and throughout the detailed description, the invention is described with respect to normal incidence of the illumination on the sheet. This is only for convenience of exposition. Such incidence, or measurement of light reflected (diffracted) perpendicularly to the sheet results in height independence of the measurement. However, non-incident incident and reflected light may be used in some less preferred embodiments of the invention.

The delay between the detection of front edge by sensor 20 and the detection of rear edge by sensor 24 is given by $T_L = (L+W)/V$, wherein L is the object length (e.g., paper length), W is the beamwidth along the motion measurement direction and V the object velocity. This relation enable to calculate the object length, irrespective of it's spacing from the grating (i.e., independent from H).

It should be understood that while optimal accuracy is achieved by using separate sensors for leading and trailing edge detection, a single detector will detect both leading and trailing edges, with lesser accuracy. Such a single detector can also be used, with proper filtering, to detect presence.

Fig. 3 shows the optional use of sensor 22 to detect the presence of that part of object 9 illuminated by the illuminating beam, regardless of it's motion (e.g., jammed paper in a copying machine). The rays impinging on sensor 22 show the acceptance angle of the sensor, as determined by the sensor dimensions and the lens focal length. The determination of object presence is based on the output of sensor 22, which is responsive to the energy reflected from the object within the acceptance angle of sensor 22. Unlike sensors 20 and 24, sensor 22 is sensitive to reflected energy and not to the LO or movement. Lines 100 and 102 show the

maximum angular deviation of beams from any portion of paper 9 which are accepted by sensor 22.

It should be understood that sensors 20 and 24 detect *Doppler* shifts only over that portion of their surface at which the LO is also present. Sensor 22 is not so restricted, such that the entire area of the sensor is useful for the measurement of power reflected from the surface of paper 9.

A schematic drawing of a detection circuit 50 for use with the detector of Figs. 1-3 is shown in Fig. 4. The basic channel for front-edge detection includes a transimpedance amplifier 52 that transforms photodiode current from sensor 20 into voltage, a band-pass filter and amplifier 54 that amplifies the range of frequencies expected according to the expected Doppler shift. It also includes an energy detector 56 to detect the energy in this Doppler band. The output is set to 'high' logic level by comparator 58, when the edge of a moving paper enters the beam. The comparison level of comparator 58 is shown as a voltage V_T. V_T is preferably chosen to be somewhat above the noise level to avoid false triggering. Preferably additionally, a comparator with hysteresis (Schmitt trigger) is used to avoid the effects of varying power level. The output stays high as long as the paper moves and reflection from the paper interferes with the local oscillator beam onto sensor 20. The output signal of energy detector 56 may be differentiated prior to comparison by comparator 58.

A Schmitt-trigger 60 (or other comparator) and a frequency counter or detector 62 are preferably used to determine the object translation or velocity, respectively, when a measurement of such translation or velocity is desired. The comparator hysteresis or threshold is preferably set at a very low, noise determined voltage.

The rear-edge detection (based on sensor 24) is similar to the front-edge detection, except that the edge is identified as loss-of-power at the output of a power detector 64. Also, a rear edge detector band pass filter (BPF) 66 can be controlled responsive to the measured Doppler frequency of the front edge detector by a control line 68, to reduce noise. Preferably, the pass limits of filters 54 and 66 are matched to the expected Doppler frequency range, to limit noise.

The power in a 'presence' amplifier 70 is amplified and compared (in comparator or Schmitt trigger 76) to a background-rejection threshold V_B, to identify the presence of an object illuminated by the illumination beam, irrespective of it's motion.

Circuit 50 also includes decision logic 74 which utilizes the outputs of the elements 62, 58, 78 and amplifier 70 to determine the velocity, front edge entry time, rear edge exit time and